



ECONOMIC RESEARCH
FEDERAL RESERVE BANK OF ST. LOUIS
WORKING PAPER SERIES

Information Shares in the U.S. Treasury Market,

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| Authors | Bruce Mizrach, and Christopher J. Neely |
| Working Paper Number | 2005-070E |
| Revision Date | October 2007 |
| Citable Link | https://doi.org/10.20955/wp.2005.070 |
| Suggested Citation | Mizrach, B., Neely, C.J., 2005; Information Shares in the U.S. Treasury Market,, Federal Reserve Bank of St. Louis Working Paper 2005-070. URL https://doi.org/10.20955/wp.2005.070 |

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| Published In | Journal of Banking & Finance |
| Publisher Link | https://doi.org/10.1016/j.jbankfin.2007.10.007 |

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Information Shares in the U.S. Treasury Market

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This Draft: September 30, 2007

Abstract:

This paper characterizes the tatonnement of high-frequency returns from U.S. Treasury spot and futures markets. In particular, we highlight the previously neglected role of the futures markets in price discovery. The highest futures market shares are in the longest maturities. The estimates of 5-year and 10-year GovPX spot market information shares typically fail to reach 50% from 1999 on. The GovPX information shares for the 2-year contract are higher than those of the 5- and 10-year maturities but also decline after 1998. Standard liquidity measures, including the relative bid-ask spreads, number of trades, and realized volatility are statistically significant and explain up to 21% of daily information shares. The futures market gains information share in about 1/4 of the events where public information is released, but days of macroeconomic announcements rarely explain information shares independently of their effects on liquidity.

Keywords: information shares; Treasury market; microstructure; GovPX; futures; price discovery.

JEL Codes: G14; G12; D4; C32;

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1. Introduction

The market for U.S. Treasury securities provides an excellent context in which to study price discovery—the process by which information is incorporated into prices. The Treasury market is highly liquid and receives a steady flow of public information, such as scheduled macroeconomic announcements. Throughout the 1990s, GovPX consolidated tick-by-tick transactions data from a high proportion of the spot market, enabling econometricians to study the price discovery process. These characteristics of the Treasury market make it a natural place to study how heterogeneous traders impound new information into prices.

There have been two major lines of research on Treasury market microstructure. The first of these has focused on the impact of public information around macroeconomic announcements. The second strand of research has studied how quotes and trading activity reveal private information.

Fleming and Remolona (1997, 1999a) did the seminal work on how Treasury prices respond to economic news, examining how GovPX trading activity and prices react to the surprise components of macroeconomic releases. Following this line of research, Fleming and Piazzesi (2005) looked at the high-frequency behavior of Treasury note yields around FOMC announcements from 1994 to the end of 2004. They reconcile the high volatility of such yields with modest average effects of announcements by showing that the reaction of Treasury yields depends on the shape of the yield curve at the time of announcement. They found that the market reaction to FOMC inter-meeting moves is sluggish.

Additional research has investigated how prices react to order flow. Green (2004) looks at the informational role of trading around announcements. Using the Madhavan, Richardson and Roomans (MRR, 1997) model and GovPX data on the most recently issued 5-year Treasury note, from July 1, 1991, through September 29, 1995, Green finds that trades have a greater informational role in the 15 minutes after macroeconomic announcements and that order flow reveals information about the riskless rate. With a vector autoregressive (VAR) model and GovPX data from January 1992 through December 1999, Brandt and Kavajecz (2004) find that order flow imbalances (excess buying or selling pressure) account for up to 26% of the day-to-day variation in U.S. Treasury yields on non-announcement days. The paper also finds that price discovery is important to understanding the yield curve. Cohen and Shin (2003) estimate a VAR on quotes and signed trades of 2-year, 5-year and 10-year on-the-run U.S. Treasury notes. They confirm the results of Hasbrouck (1991)—order flow causes prices—but found that there is often a curious positive feedback effect: price

increases seem to generate buying pressure during periods of market stress and volatility.

Not all Treasury market microstructure research investigates the reactions to announcements or order flow. Boni and Leach (2004) also use the GovPX data from October 1997 to investigate depth discovery—the process by which traders determine the quantity that can be traded at a particular price—in Treasury markets.

The bond market microstructure literature, with a few exceptions, has largely ignored the important futures market in Treasury instruments, however, leaving the findings incomplete. Tse (1999) finds that the Tokyo market reveals more information about Japanese government bond futures than does the London market. Upper and Werner (2002) examine how Bund price discovery shifts from spot to futures markets at times of crises. Brandt, Kavajecz, and Underwood (2006) show that futures and spot market order flow are useful in predicting daily returns in each market and that the type of trader influences the effect of order flow. Campbell and Hendry (2006) look at the 10-year bond and futures contracts in both the United States and Canada.

The goal of this paper is to model interaction between the GovPX spot markets and the Chicago Board of Trade (CBOT) futures market. Our paper extends the price discovery literature in several ways. This paper is the first to estimate the Hasbrouck (1995) and Harris, McNish and Wood (2002) price discovery measures for several maturities of U.S. Treasury instrument spot and futures markets. We establish that the futures and the basis adjusted on-the-run Treasury securities are cointegrated. This enables us to compare the price discovery from liquid spot with futures instruments and to compute the speed of adjustment to equilibrium. The futures data contribute substantially to price discovery, often dominating the GovPX market. Studies that exclude futures data might be misleading or incomplete.

After characterizing the information share measures, we document and explain the cross-sectional and intertemporal variation in those measures. While information shares vary substantially day-to-day, a given market's relative share of trades, spread size and realized volatility strongly explain its contribution to price discovery. This enables us to estimate information shares out-of-sample or when there is missing data.

We find that days of macroeconomic announcements modestly raise futures market information shares, particularly in a one-hour window after the announcement. Macro announcements appear to have their effects on information shares through liquidity/volatility variables, however. The latter variables subsume the effects of news releases. In contrast, FOMC-related events have

essentially no effect on information shares.

2. A Model with Multiple Markets

Price discovery seeks to identify which of several markets tend to incorporate permanent changes in asset prices first. That is, to what extent does a market “discover” the price to which all markets for the security are tending in the long run.

There are two standard methods by which one can apportion weights to markets in the process of price discovery: The Hasbrouck (1995) information share (H) and the Harris, McInish and Wood (2002) measure (HMW) which utilizes the Gonzalo and Granger (1995) permanent-transitory decomposition. The Hasbrouck share H is the contribution of shocks to market i on the total variance of the permanent component of prices. The HMW weights can be interpreted as the limits of the changes in the price with respect to the elements of the shock vector, as the time horizon goes to infinity.

Both of these methods start with the observation that asset prices appear to be very persistent, and one is generally unable to reject that such prices are $I(1)$. Arbitrage prevents prices of the same security from diverging in different markets, however. $I(1)$ behavior in individual prices, combined with stationary linear combinations of those prices, implies that prices of similar assets in different markets can be considered a cointegrated process.

2.1 Error-correction model

Hasbrouck (1995) developed the standard measure of price discovery for multiple markets. He argued that prices $p_{i,t}$ in market i should deviate from some unobservable fundamental price, p_t^* , only by some transient noise:

$$p_{i,t} = \beta_{i,t} p_t^* + \xi_{i,t}. \quad (1)$$

In the case of the Treasury market, a range of maturities can be delivered at expiry, so our model extends Hasbrouck to allow for basis adjustments between similar but not identical instruments.¹

¹ It is quite common with derivative securities to have multiple assets which can be delivered at expiry, and neither the Hasbrouck model nor the price discovery framework requires the securities to be identical. For the decomposition we propose in Section 2.4, we only need the prices to be cointegrated. This relationship exists theoretically because of arbitrage between highly correlated substitutes, and we confirm the cointegration link empirically.

The fundamental price itself is assumed, like before, to be a random walk:

$$p_t^* = p_{t-1}^* + \eta_t. \quad (2)$$

The error terms may be contemporaneously and serially correlated,

$$cov(\xi_{i,t}, \xi_{j,t-k}) = \omega_{i,j,t-k}, \quad (3)$$

with $Var(\eta_t) = \sigma_\eta^2$.

If the price series are $I(1)$, cointegrated, and have an r^{th} order VAR representation,

$$p_t = \Phi_1 p_{t-1} + \Phi_2 p_{t-2} + \cdots + \Phi_r p_{t-r} + \varepsilon_t,$$

it follows that returns,

$$r_t = \begin{bmatrix} p_{1,t} - p_{1,t-1} \\ \vdots \\ p_{N,t} - p_{N,t-1} \end{bmatrix} = \Delta p_t, \quad (4)$$

which share a common random walk fundamental, have the convenient Engle-Granger (1987) error-correction representation,

$$\Delta p_t = \alpha z_{t-1} + A_1 \Delta p_{t-1} + \cdots + A_r \Delta p_{t-r-1} + \varepsilon_t, \quad (5)$$

where z_t is the error-correction term of rank $N - 1$.

In most price discovery applications, z_t is a vector of differences in prices between markets. Because futures prices are not directly comparable to spot bond prices, z_t includes coefficients $\beta_{i,t}$ that adjust for daily changes in basis,

$$z_{t-1} = \begin{bmatrix} p_{1,t-1} - \beta_2 p_{2,t-1} \\ \vdots \\ p_{1,t-1} - \beta_N p_{N,t-1} \end{bmatrix}. \quad (6)$$

The coefficients, α ($\alpha > 0$), reveal the speed with which deviations between the prices in market 1 and the other markets are corrected. Other things equal, a larger α_j indicates a greater speed of correction to the price in market 1 and less price discovery in market j .

2.2 Futures basis adjustment

A bond is a security that pays a known income (the coupon yield). If one is trading at time t , ($t < T < N$), there are two ways to obtain an n -year bond, maturing at N , to hold in one's portfolio at time T : (1) buy the asset in the spot market, at price $p_{t,N}$, and hold the bond until T ; or (2) buy

the n -year bond through a futures contract for delivery at T , at price $f_{t,T,N}^{cash}$.² Buying the bond in the spot market requires an immediate outlay of cash but garners the purchaser the accrued interest on the bond from purchase to delivery. The absence of arbitrage ensures the following relation between the cash futures price and the cash spot price,

$$\frac{f_{t,T,N}^{cash}}{(1 + r_{t,T})^{T-t}} = p_{t,N}^{cash} - I_{t,T,N}, \quad (7)$$

where $I_{t,T,N}$ is the (time t) value of accrued interest on the bond from the trading day (t) to the contract delivery date (T). The “cash” superscripts denote cash prices, not quoted prices. The cash price of a bond is the quoted price plus accrued interest since the last coupon payment.

$$p_{t,N}^{cash} = p_{t,N}^q + AI_{t,N}, \quad (8)$$

where the superscript q denotes quoted prices, and $AI_{t,N}$ is the accrued interest, since the last coupon payment, on the given n -period bond. Note that the interest accrued between the trading day and the expiration day, $I_{t,T,N}$, is distinct from the interest accrued from the last coupon payment to the trading day, $AI_{t,N}$.

In addition to distinguishing between cash and quoted prices, the CBOT allows the party with a short position to pick which bond it will deliver. The cash received for futures settlement depends on which bond is delivered through a *conversion factor* and the accrued interest on the particular bond at the time of settlement. For a given deliverable bond, maturing at N , the cash received by the party with the short position is as follows:

$$f_{t,T,N}^{cash} = f_{t,T,N}^q CF_N + AI_{t,N}, \quad (9)$$

where CF_N is the CBOT’s conversion factor that depends on which bond is actually delivered.

Parties with the short position will pick the cheapest-to-deliver bond by minimizing the net cost of delivery (purchasing the bond in the spot market less cash received) over all eligible bonds,

$$\begin{aligned} \min_{\tilde{N}} \left(p_{t,\tilde{N}}^{cash} - f_{t,T,\tilde{N}}^{cash} \right) &= \min_{\tilde{N}} \left[p_{t,\tilde{N}}^q + AI_{t,\tilde{N}} - \left(f_{t,T,\tilde{N}}^q CF_{\tilde{N}} + AI_{t,\tilde{N}} \right) \right] \\ &= \min_{\tilde{N}} \left[p_{t,\tilde{N}}^q - f_{t,T,\tilde{N}}^q CF_{\tilde{N}} \right], \end{aligned} \quad (10)$$

where \tilde{N} indexes the eligible bonds. The bond that minimizes this quantity is known as the cheapest-to-deliver (CTD).

Assuming that the CTD bond is known and matures at N , (7) implies the following relation

² Here we assume away any difference between forward and futures prices by assuming that the futures price is paid at delivery rather than being marked to market.

for quoted spot and futures prices:

$$\frac{f_{t,T,N}^q CF_N + AI_{T,N}}{(1 + r_{t,T})^{T-t}} = p_{t,N}^q + AI_{t,N} - \frac{I_{t,T,N}}{(1 + r_{t,T})^{T-t}} \quad (11)$$

Therefore, the relation between quoted spot and futures prices (11) for the conversion-factor adjusted n -period bond is approximately linear, within a day,

$$\frac{f_{t,T,N}^q CF_N}{(1 + r_{t,T})^{T-t}} = p_{t,N}^q + AI_{t,N} - \frac{AI_{T,N}}{(1 + r_{t,T})^{T-t}} - \frac{I_{t,T,N}}{(1 + r_{t,T})^{T-t}}. \quad (12)$$

The only quantity in (12)—besides the quoted spot and futures prices—that varies within the day is the discount rate, $(1 + r_{t,T})^{T-t}$. If this quantity is not too variable within the day, compared to spot and future prices, then intraday spot and futures prices are effectively cointegrated.³ This discount rate assumption seems reasonable for our relatively close-to-maturity futures contracts compared with the prices of the much longer time-to-expiry of the 2-, 5- and 10-year bonds.

A difficulty with directly using the relation in (12) is that the CTD bond is almost always an off-the-run bond, but these bonds are too illiquid to contribute much to price discovery. The most liquid spot market instruments (by far) are on-the-run bonds. We would like to compare price discovery in the futures market to the most liquid, but still closely related, on-the-run spot market instruments. To compare on-the-run bond prices to futures prices, we need to assume that the on-the-run and the CTD off-the-run bond prices are cointegrated.⁴ We assume that a linear relation links the prices of these bonds of similar maturity,

$$p_{t,N^*}/CF_{N^*} = \beta_n p_{t,N}/CF_N. \quad (13)$$

where N^* denotes quantities pertaining to the CTD bond, N pertains to the on-the-run bond and β_n is adjusted each day in our estimation. The conversion factors are constant within our daily estimation period. Later, we will show that the use of daily betas is innocuous. There is no evidence of intraday variation in the β_n s and that the qualitative inference is very robust to further restricting variation in β_n , including setting it equal to one.

In the case of the 2-year, the interpolation range is only 3 months. 5-year bond delivery range is also quite narrow, between 4 years and 2 months and 5 years and 3 months. In the case of the

³ In addition to the cointegration of the spot and futures prices, the daily return series are highly correlated. Daily spot and futures returns have a correlation of 76.2% for the 2-year note, 93.0% for the 5-year, and 96.2% for the 10-year. Given that the spot and futures prices are noisy estimates of the unobserved equilibrium price at any given time, these are very high correlations.

⁴ The existence of the off-the-run puzzle indicates that one would expect the on- and off-the-run prices to move together, for the bonds to be close substitutes. Note that our cointegration requirement does not preclude a level difference between on- and off-the-run bonds.

10-year, it is between 6.5 years and 10 years. In any case, the assumption of a linear, cointegrating relation is ultimately an empirical one which we will test.

2.3 Cointegration between the on-the-run spot and adjusted futures prices

Our analysis of the information shares requires the spot and futures prices to be cointegrated. Arbitrage between spot and futures markets will ensure cointegration between the cheapest-to-deliver (CTD) bond and the futures contract. Arbitrage will also closely link prices of the cheapest-to-deliver (CTD) bond and the close-in-maturity on-the-run instrument. Therefore the futures price and the on-the-run prices should be closely linked. We next show that the on-the-run bonds and the conversion-factor adjusted futures prices are, in fact, cointegrated.

Denote by \hat{u}_t the estimated difference between on-the-run Treasury price $p_{t,N}$ and the basis adjusted futures price, $CF_N f_{t,N}^q$,

$$\hat{u}_t = p_{t,N}^q - \hat{\beta}_n CF_N f_{t,N}^q. \quad (14)$$

Note that the conversion factor pertains to the on-the-run instrument.

We need to show that \hat{u}_t is a stationary process. We follow the suggestion of Engle and Granger (1987) to use the augmented Dickey-Fuller (ADF) test on the residuals,

$$\Delta \hat{u}_t = \phi_0 \hat{u}_{t-1} + \sum_{i=1}^k \phi_i \Delta \hat{u}_{t-i} + \varepsilon_t. \quad (15)$$

Pesavento (2004) shows that the ADF test has good size and reasonable power properties for our sample size, 400 daily 1-minute returns, and R^2 of around 0.20. A rejection of the unit root, using the t -ratio on ϕ_0 , indicates that the spot and futures markets are cointegrated. Even with our daily sample, we can reject the null of no cointegration, in 98.7% of the cases for the 2-year, 98.5% for the 5-year, and 94.2% for the 10-year. We find this evidence very persuasive, given the well known difficulty of rejecting the unit root hypothesis for alternative hypotheses that imply persistent data.

Establishing that the basis adjusted futures price and the on-the-run spot market bond appear to be cointegrated is, to our knowledge, a new result.

2.4 Information shares

2.4.1 Hasbrouck measure

Hasbrouck (1995) introduced the notion of information share, which is derived from the Stock-Watson (1988) permanent/transitory decomposition. The vector moving average (VMA) represen-

tation for returns provides the elements necessary to calculate the information share,

$$\Delta p_t = \Psi(L)\varepsilon_t. \quad (16)$$

Hasbrouck notes that the sum of the $N \times N$ moving average matrices, $\Psi(1) = \sum_{j=0}^{\infty} \Psi(L^j)$, represents the long-run multipliers, the permanent effect of the shock vector on all the cointegrated security prices.

Fortunately, the error-correction framework provides the long-run multipliers, $\Psi(1)$, far more compactly than summing the VMA coefficients. Baillie et al. (2002) show that

$$\Psi(1) = \beta_{\perp} \pi \alpha'_{\perp} = \pi \begin{bmatrix} \gamma_1 & \cdots & \gamma_N \\ \vdots & & \vdots \\ \gamma_1 & \cdots & \gamma_N \end{bmatrix}, \quad (17)$$

where π is a scalar factor under our assumption of a single common factor. β_{\perp} and α_{\perp} are the *orthogonal complements*⁵ of the original parameter vectors in (6) and (5). Because the prices are cointegrated, each error term must have the same long-run impact on prices. This means that all the rows in (17) are identical.

To obtain the contributions of shocks to market i on the permanent component of prices, we follow Hasbrouck and perform a Choleski decomposition on $\Omega = E[\varepsilon_t \varepsilon'_t]$, the $N \times N$ covariance matrix, to find a lower triangular matrix M , whose i, j^{th} element we denote m_{ij} , such that $MM' = \Omega$. We now define, in the same manner as Baillie et al. (2002), the Hasbrouck information share for market j ,

$$H_j = \frac{\left[\sum_{i=j}^n \gamma_i m_{ij} \right]^2}{\left[\sum_{i=1}^n \gamma_i m_{i1} \right]^2 + \left[\sum_{i=2}^n \gamma_i m_{i2} \right]^2 + \cdots + (\gamma_n m_{nn})^2}. \quad (18)$$

where the γ_i are the elements of row i of the long-run multipliers in (17).

The denominator is the total variance of the permanent component of the one-step price change; it can equivalently be written as $\gamma' \Omega \gamma$, where γ is the $N \times 1$ vector consisting of the γ_i 's. The numerator is the j^{th} shock's contribution to the variance of the permanent component of prices, including the covariance of the j^{th} shock with shocks $\{j+1, j+2, \dots, N\}$. That is, market j 's information share is the proportion of variance in the common factor that is attributable to shocks in market j .

The Hasbrouck information share is closely related to the forecast error decomposition in conventional VAR modeling. Like that decomposition, it may be sensitive to the ordering of the

⁵ The orthogonal complement of a vector α is denoted α_{\perp} and solves the linear equation $\alpha' \alpha_{\perp} = 0$.

variables in the VAR – which is an implicit identification scheme – if the errors ε_t are contemporaneously correlated. That is, the Hasbrouck share of the j^{th} market will generally include the variance of the j^{th} shock plus the contribution of the covariance of the j^{th} shock with later shocks. Putting a variable earlier in the ordering will increase its information share. In a two-variable system, the two possible orderings will provide upper and lower bounds on the information shares of the variables. In larger systems, the first and last orderings will give the greatest/least possible information share for a given variable.

Systems with correlated errors create inherent uncertainty about information shares. This uncertainty reflects the fact that one simply cannot identify price leadership between two markets when the prices in those markets move together during the sampling interval. Longer sampling intervals create higher correlations between markets, increasing the ambiguity about information shares. Hasbrouck’s (1995) study used a one-second sampling interval and found that the lower and upper bounds were very close. Most studies use longer sampling intervals and find that the lower/upper bounds are much wider and that inference depends to some degree on the ordering of the variables. This paper reports both the Hasbrouck lower- and upper-bound (H_L and H_U) estimates for the GovPX market share.

2.4.2 Harris-McInish-Wood measure

The literature contains an active and ongoing discussion of the interpretation of the information share. Harris, McInish, and Wood (2002) have argued for the use of an alternative decomposition based on the Gonzalo and Granger (1995) common-factor approach.

Gonzalo and Granger decompose the price vector into permanent, g_t , and transitory, h_t , components,

$$p_t = \theta_1 g_t + \theta_2 h_t, \quad (19)$$

where the permanent component is a linear combination of current prices, $g_t = \Gamma p_t$. The additional identifying assumption that h_t does not Granger-cause g_t implies that $\theta_1 = \beta_{\perp} \alpha'_{\perp} = (\gamma_1, \gamma_2, \dots, \gamma_N)'$, where the γ_i are defined in (17). The weights given to price discovery are defined as the partial derivative of the permanent component with respect to shocks. In our notation, we define them as

$$H_{MW} = \frac{\gamma_j}{\sum_{i=1}^N \gamma_i}. \quad (20)$$

What is the relation between the Hasbrouck information share and the H_{MW} permanent-

transitory price weights? Both measures are defined in terms of the orthogonal complement α_{\perp} to the cointegrating vector, but they differ in how this information is used. De Jong (2002) points out that the Hasbrouck information share vector includes the γ 's, but they are normalized by the total variance of the common trends innovations. The *HMW* weights can be interpreted as the limit of the change in the price with respect to the shock vector, as the time horizon goes to infinity. H measures each shock's share of the variance of the one-step-ahead permanent component. Uncorrelated shocks and similarly sized shocks (across markets) will equalize the measures. De Jong (2002) compares the relation between the two measures to the relation between a regression coefficient (*HMW*) and a partial R^2 (H).

Which measure is better? De Jong says that both measures have their merits. The *HMW* measure permits one to reconstruct the efficient price history from the full innovation vector while Hasbrouck's information share describes how much price variation that the shocks to each market explain. De Jong believes H to be a more useful definition of price discovery. Baillie et al. (2002) believe that Hasbrouck's method has more general appeal and interpretation. But Harris, McInish, and Wood (2002) argue that the *HMW* measure recovers the true microstructure in a wide range of financial market models. As Lehmann (2002) argues, the VECM is a reduced form, so examples can be constructed in which either measure is arbitrarily good or bad. Lehmann concludes that it is sensible to report both estimates.

2.5 Bivariate case

The general model simplifies quite a bit in the case $N = 2$, as in our study of the relative information shares of the GovPX screen-based market and the futures market. We can write the error-correction representation as follows:

$$\begin{bmatrix} \Delta p_{1,t} \\ \Delta p_{2,t} \end{bmatrix} = \begin{bmatrix} c_1 - \alpha_1(p_{1,t-1} - \beta_1 p_{2,t-1}) \\ c_2 + \alpha_2(p_{1,t-1} - \beta_1 p_{2,t-1}) \end{bmatrix} + \begin{bmatrix} \sum_{j=1}^r -A_{1,j}^1 \Delta p_{1,t-j} + A_{1,j}^2 \Delta p_{2,t-j} \\ \sum_{j=1}^r -A_{2,j}^1 \Delta p_{1,t-j} + A_{2,j}^2 \Delta p_{2,t-j} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}. \quad (21)$$

We follow Baillie, et al. (2002) by constructing information shares from the error-correction coefficients α and the elements of the covariance matrix,

$$\Omega = \begin{bmatrix} \sigma_{1,\varepsilon}^2 & \rho \sigma_{1,\varepsilon} \sigma_{2,\varepsilon} \\ \rho \sigma_{1,\varepsilon} \sigma_{2,\varepsilon} & \sigma_{2,\varepsilon}^2 \end{bmatrix}. \quad (22)$$

After taking the Choleski decomposition, they obtain

$$M = \begin{bmatrix} \sigma_{1,\varepsilon} & 0 \\ \rho \sigma_{2,\varepsilon} & \sigma_{2,\varepsilon}(1 - \rho^2)^{1/2} \end{bmatrix}, \quad (23)$$

where $MM' = \Omega$.

The Hasbrouck upper-bound information share of the first asset in the VAR is

$$H_1 = \frac{(\alpha_2 \sigma_{1,\varepsilon} + \alpha_1 \rho \sigma_{2,\varepsilon})^2}{(\alpha_2 \sigma_{1,\varepsilon} + \alpha_1 \rho \sigma_{2,\varepsilon})^2 + (\alpha_1 \sigma_{2,\varepsilon} (1 - \rho^2)^{1/2})^2}. \quad (24)$$

The Harris-McInish-Wood information share of the first asset in the VAR is

$$H_{MW_1} = \frac{\alpha_2}{\alpha_1 + \alpha_2}. \quad (25)$$

Note that if variances are equal ($\sigma_{1,\varepsilon} = \sigma_{2,\varepsilon}$) and the covariance matrix is diagonal ($\rho = 0$), the measures should be quite close.

3. Data

3.1 GovPX

A growing literature explores the screen-based electronic trading markets in U.S. Treasuries. The GovPX trading platform consolidated quotes and trades from nearly all the major inter-dealer brokers.⁶ Fleming (2003) describes the characteristics of liquidity in this market in the period from 1997 to 2000. Mizrach and Neely (2006) characterize the shift of the interdealer market to electronic trading.

Three types of Treasury securities are traded on GovPX. The *on-the-run* Treasury is the most recently auctioned security of a particular maturity. Previous issues are considered *off-the-run*. The *when-issued* market consists of trading in securities that are about to be auctioned or are still to be delivered.

We will look at the on-the-run 2-year, 5-year, and 10-year notes, the most active securities in the GovPX data set, over the period October 1, 1995, to March 30, 2001. These instruments are liquid and we can reliably identify⁷ trades in GovPX in this period.

[INSERT Figure 1 HERE]

Figure 1 shows that most trades are in on-the-run securities. In the 2-year note, for example, there were an average of 348 on-the-run, 203 off-the-run, and 29 when-issued trades per day in 1997.

⁶ The contributing brokers during 1995-2001 included Garban-Intercapital, Garvin Guy Butler, Hilliard Farber, RMJ, and Tullett & Tokyo Liberty.

⁷ After March 30, 2001, GovPX no longer reports aggregate trading volume. It is difficult after this point to identify trades uniquely.

The volume of on-the-run trading shows no strong trends from 1995 to 1998 but falls substantially after 1998 for the 5- and 10-year notes. Trading volume in the 2-year note similarly falls after 1999.

There is trading in nearly 22 distinct off-the-run issues per day, making each individual security rather illiquid. The off-the-run Treasuries typically trade at a discount to the on-the-run security of similar maturity. The academic and practitioner communities debate whether one can exploit these differences through arbitrage. The off-the-run puzzle has been explored most recently in a theoretical paper by Vayanos and Weill (2005) and in empirical papers by Krishnamurthy (2002) and Barclay, Hendershott, and Kotz (2006). GovPX trading in off-the-run securities tends to decline throughout the sample.

When-issued trading is the smallest portion of the GovPX market. The overall number of trades can mislead, though. When-issued trading is intense primarily in short periods prior to auctions. For example, on October 25, 1995, there were 511 trades and a total volume of 5,207 bonds in the when-issued 5-year note. When-issued trading in GovPX declines substantially over the sample and is negligible by 2001.

The reasons for the decline in GovPX trading over the sample are not entirely clear. The reduction in federal deficits from 1992 to 2000 reduced the size of the bond market pie, but Mizrach and Neely (2006) note that primary dealer transactions increased from 1995 to 2001. It seems more likely that the introduction of electronic communications networks (ECNs), such as eSpeed in 1999 and Brokertec in 2000, contributed to the decline in GovPX trading.

3.2 Futures

We incorporate futures prices into our study to investigate the relative information content of the spot and futures markets. Futures markets permit small trades of standardized assets at relatively low cost or settlement risk. The information content of spot and futures trades differs from market to market. In stock markets, for example, futures prices generally incorporate information about market trends more rapidly than those of individual stocks (e.g., de Jong and Nijman (1997)). In foreign exchange, the evidence is mixed. Hutcheson (2003) finds that the highly liquid spot market leads the futures prices. Martens and Kofman (1998) find that indicative Reuter's FXX spot market quotes do not subsume the futures market quotes and Rosenberg and Traub (2005) report that futures order flow seems to dominate in price discovery. Ex ante, it is not obvious whether spot or derivatives markets should dominate in bond price discovery. Failing to account for futures prices in a study of Treasury market price discovery could lead to mistaken inference.

We use 2-, 5- and 10-year historical futures transactions prices, time-stamped to the second.⁸ These notes trade on the CBOT in an open outcry auction from 8:20 AM to 3:00 PM Eastern time. We have floor session data from all three instruments.

This paper follows the usual practice of splicing futures data at the beginning of contract expiry months: March, June, September and December. For example, settlement prices for the futures contract expiring in March 1996 are collected for all trading days in December 1995 and January and February 1996. Then data pertaining to June 1996 contracts are collected from March, April and May 1996 trading dates. We follow a similar procedure for the September and December contracts. This method avoids pricing problems near final settlement that result from illiquidity (Johnston, Kracaw and McConnell (1991)).

Figure 2 shows that, in this time period, the most liquid futures market is the 10-year bond with an average of 560 trades per day over the whole sample. The 5-year is second with an average of 280 trades per day. The 2-year is a distant third with 47 trades per day.

[INSERT Figure 2 HERE]

There are increasing numbers of trades in all futures contracts during the 1995-2001 sample. We will see that this trend is mirrored in increasing futures market information shares.

4. Estimates of the Information Shares

We report the HMW and both the Hasbrouck lower- and upper-bound estimates of the GovPX market information share. To compute the Hasbrouck upper (lower) bound, we place the spot market first (second) in the bivariate VAR. We examine the three most liquid spot market securities, the 2-year, 5-year and 10-year on-the-run spot bonds, and their maturity matched futures contracts.

Figure 3 shows the annual averages from 1995 to 2001 of daily information shares.

[INSERT Figure 3 HERE]

Table 1 shows the annual averages for the information shares, illustrated in Figure 3, and the α and β coefficients from the VARs. We report bootstrap standard errors for each.

We explored two ways in which the β 's might vary during the day. The first model we considered was where β changed between the morning, 08:20 to 12:00 and then from 12:00 to 15:00. The

⁸ Contract details on the Treasury futures may be found at <http://www.cbot.com/cbot/pub/page/0,3181,830,00.html>.

second model permitted each β to be a function of a constant and a time trend. Statistical tests failed to reject a constant β against these alternatives only about as often as one would expect under the null.

The Hasbrouck and HMW estimates of the GovPX information shares display common patterns across instruments and over time. First, the GovPX information share measures are negatively related to the maturity of the instruments and the trading activity in the futures market. That is, the GovPX share is highest for 2-year notes, where it ranges from 42 to 86 percent, depending on the measure and the time period. The GovPX share for 5-year notes is lower, varying from 21 to 72 percent. Finally, the GovPX shares are lowest for the 10-year bonds; the Hasbrouck upper bound never exceeds 50%.

The second common pattern is that all the GovPX information shares rise from 1995, peaking in 1998. The Hasbrouck estimates for the 2-year and 5-year notes indicate that most price discovery occurs in the spot market in 1998. The H_U estimate of the GovPX share for the 10-year bond hovers just below 50 percent in that year.

[INSERT Table 1 HERE]

After 1999, GovPX trading volume and information shares decline for all three markets. For example, by 2001, GovPX performs only 27% of the price discovery in the 5-year market, according to the H_U measure. Likewise, the H_U estimate of the GovPX share of the 10-year market declines very rapidly after 1998, falling to only 17% in 2001.⁹ The Hasbrouck estimates of the GovPX share of the 2-year market also declines but GovPX retains the majority share of the shortest maturity market, for both Hasbrouck measures. The HMW estimate of the GovPX share of the 2-year market is somewhat lower in 2001, at 42%.

To assess the robustness of our results to the specification of β , we reestimated information shares under two alternative assumptions: 1) β equal to its annual mean value from Table 3 for *each* day of the year; 2) $\beta = 1$, removing it from the analysis. These changes produce very modest (0 to 10 percent) level shifts in the average 2-year information shares but very similar information shares for the 5- and 10-year cases. Neither choice for β affected the qualitative pattern of a gradual rise and then decline of the GovPX market.

Both GovPX and futures markets influence tatonnement in the U.S. Treasury market, but the

⁹ Campbell and Hendry (2006) report a 23.3% average spot market information share across four months in 2000 for the 10-year/ 10-year combination.

growth of ECNs like eSpeed and BrokerTec, which debuted in 1999 and 2000, respectively, lead to a growing dominance of the futures market in price discovery.¹⁰

[INSERT Table 2 HERE]

The parameters used to construct the price discovery measures also imply estimates of the half-lives of the deviations from equilibrium. For example, in 1995, the average partial adjustment coefficient for the 10-year spot market is 0.0424. This value implies a half-life of noisy shocks in the spot market of 16 minutes.¹¹ The average partial adjustment coefficient falls to 0.0139 in 2001, raising the half life to 49 minutes. Table 2 reports similar estimates for the 2-year and 5-year notes. For the 5- and 10-year notes, the difference between maximum and minimum half-lives is substantial. The maximum half life for the 5- and 10-year notes are more than two and three times the level of the minimum half lives.

Adjustment in the futures market is quicker, never taking more than 15 minutes. For the actively traded 5- and 10-year contracts, adjustment occurs in 7 minutes or less. These estimates provide an intuitive measure of the time necessary to correct disequilibria.

5. Predictability of Information Share

What observable characteristics of market structure explain information shares? Yan and Zivot (2004) address this question in a structural VAR. We consider the question using the time series of daily estimates of the spot market's information share, IS_t , for both the *HMW* and the upper bound¹² H_U measures. To determine whether liquidity measures explain information shares, we estimate the regression,

$$\begin{aligned} \ln(IS_{1,t}/(1 - IS_{1,t})) &= c + b_1 \ln(S_{1,t}/(S_{1,t} + S_{2,t})) + b_2 \ln(N_{1,t}/(N_{1,t} + N_{2,t})) \\ &+ b_3 \ln(RV_{1,t}/(RV_{1,t} + RV_{2,t})) + b_4 \times Trend + \varepsilon_t, \end{aligned} \quad (26)$$

where $IS_{1,t}$, represents the spot market's daily *HMW* or *H* share and $N_{1,t}$ and $N_{2,t}$ are the daily number of trades in the cash and futures market.¹³ $S_{1,t}$ and $S_{2,t}$ are the Thompson and Waller

¹⁰ Mizrach and Neely (2006) discuss the rise of Treasury ECNs.

¹¹ That is, 16 is the smallest integer, i , such that $0.5 > (1 - 0.0424)^i$.

¹² Liquidity measures also explain lower bound estimates; results omitted for brevity.

¹³ We have volume data for the spot market only; but, in any case, we found trades dominated volume in every specification.

(1988) daily average spreads, for the spot and futures markets, respectively,

$$S_t^{TW} = \sum_{i=1}^T |p_i - p_{i-1}|^+ / T^+. \quad (27)$$

T^+ is the number of non-zero changes in the transactions prices on day t .¹⁴ We transform the dependent variable to alleviate the distributional problems associated with limited dependent variables. RV is the annualized daily realized volatility based on 5-minute, linearly interpolated returns. The time trend is a simple linear trend.

We hypothesize that a smaller bid-ask spread expedites the tatonnement, $b_1 < 0$. We further consider whether greater liquidity (trades) should also contribute to a larger information share, $b_2 > 0$. Finally, noisy trades should diminish the information share, so we anticipate that $b_3 < 0$.

We filter out 1% of the days where trading activity is skewed heavily toward either the spot or futures markets. The days of disproportionate activity in futures markets are usually associated with holidays or the very end of the sample. The spot market tends to have disproportionate activity near the futures contract rollover points, when volume is shifting between futures contracts. Eliminating these outliers allows us to more precisely estimate the impact of trading activity on information shares.

[INSERT Table 3 HERE]

Table 3 illustrates that microstructure variables strongly explain the GovPX information share estimates. For both the Hasbrouck upper-bound and HMW shares, an increase in relative spread in the spot market decreases the spot-market information share in all 6 combinations. An increase in the realized volatility of the spot market also lowers information significantly across all maturities. The spot market's information share rises with its proportion of trades in the cash market, but the results are significant only for the 2- and 10-year.

The \overline{R}^2 s from equation (26) range from just 5% for the 2-year Hasbrouck estimates to 21% for the 5-year. We conclude that standard liquidity measures strongly capture daily fluctuations in the information share.

We think the ability to quickly compute a back-of-the-envelope estimate of information share will be of great practical value. For example, we are missing the data for 1999 from the CBOT for the 2-year note futures, but we can calculate an estimate of the GovPX information share for

¹⁴ We have only transactions prices for the futures market, so we are unable to compute quoted spreads. In the GovPX data, the correlation between quoted spreads and the Thompson and Waller spreads is 0.99.

1998. Interpolating average spreads and trades between 1998 and 2000, we obtain the following estimate for the 1999 HMW information share

$$\begin{aligned}\ln(IS_1/(1 - IS_1)) &= -3.150 - 2.601 \times -0.9351 + 0.882 \times -0.1696 \\ &\quad -1.206 \times -0.6722 + 0.107 \times 4.5 \\ &= 0.4249\end{aligned}$$

which implies an HMW share of 60.46%. Averaging the 1998 and 2000 shares would produce a lower estimate of 50.11%.

The model can also be applied out-of-sample. Using actual futures trading activity and spreads in the 10-year note for 2002, and (optimistically) assuming that GovPX measures stay at 2001 levels, we compute a Hasbrouck upper bound of

$$\begin{aligned}\ln(IS_1/(1 - IS_1)) &= -6.612 - 2.553 \times -0.3148 + 1.263 \times -3.0921 \\ &\quad -4.463 \times -0.8045 + 0.666 \times 7.5 \\ &= -4.7186.\end{aligned}$$

which translates into an information share of less than 1%.

We next turn to how the release of public information affects information shares.

6. Macro and FOMC Announcements

The literature on Treasury microstructure has focused on the release of public information. These event studies provide an opportunity to assess the possible changes in liquidity and information shares. As Fleming and Remolona (1999b) note: “In contrast to stock prices, U.S. Treasury security prices largely react to the arrival of public information on the economy.” Brandt and Kavajecz (2004) draw a more cautious conclusion, finding that order flow imbalances can explain up to 26% of the day-to-day variation in yields on non-announcement days. Our focus here is on information shares and if they change substantially during macroeconomic and/or FOMC announcements.

Why do we control for these announcements? Because the timing of such announcements is predictable, individuals can anticipate that prices might change quickly and might choose to trade in one of the markets based on an ability to observe prices and trade rapidly. The average level of activity in the spot versus futures markets might not be informative about the market’s contribution to price discovery around the times of macro announcements. Therefore it is important to control

for such announcements in assessing the influence of trading activity and spreads on price discovery measures.

6.1 Data

We have data on the dates and times of 8 important U.S. macroeconomic announcements and 3 types of FOMC related events. One group of macro announcements is related to the labor market: (1) initial jobless claims; (2) employees on nonfarm payrolls. The second group provides information about prices: (3) consumer price index; (4) producer price index. The remaining four provide information about business cycle conditions: (5) durable goods; (6) housing starts; (7) trade balance of goods and services; and (8) leading indicators. These are the same announcements used in Green (2004), except for retail sales. We also look at (9) the FOMC announcements, (10) releases of minutes, and (11) unexpected FOMC events. All of these are predictable except the unexpected FOMC events.

Several studies, including: Fleming and Remolona (1997, 1999a), Balduzzi, Elton and Green (2001), Huang, Cai and Wang (2002), Green (2004), and Brandt, Kavacejz, and Underwood (2006), have looked at the impact of macroeconomic announcements on the spot bond market. Fleming and Remolona (1997, 1999a) find that the surprise components of macroeconomic announcements are associated with the largest increases in trading volume and the largest price shocks in the GovPX bond market (all instruments) from August 23, 1993, to August 19, 1994. Balduzzi, Elton and Green (2001) find that 17 news releases influence bonds of various maturities in different ways. The adjustment to news occurs within one minute and bid-ask spreads return to normal values after five to 15 minutes, but increases in volatility and trading volume persist. Huang, Cai and Wang (2002) study trading patterns, announcement effects and volatility-volume relations in the trading behavior of primary dealers in the 5-year Treasury note inter-dealer broker market. Brandt, Kavacejz, and Underwood (2006) control for macroeconomic announcements in estimating the impact of bond market order flow on prices. Boukus and Rosenberg (2006) examine the effect of FOMC minutes releases on the Treasury yield curve.

Ederington and Lee (1993) examine the impact of monthly economic announcements on Treasury bond futures prices. The employment, PPI, CPI and durable goods orders releases produce the greatest impact of the 9 significant announcements, out of 16 studied. Andersen, Bollerslev, Diebold and Vega (2007) study the reaction of international equity, bond and foreign exchange markets to U.S. macroeconomic announcements.

The only paper to look directly at bond market information shares during times of stress is Upper and Werner (2002). Comparing relatively illiquid cheapest-to-deliver German Bund spot market prices to the futures market, their paper finds that the spot market contribution to price discovery during the 1998 Long Term Capital Management crisis is essentially zero.

6.2 Information share on announcement days

To investigate whether information shares differ from normal on the days of macroeconomic announcements, we regress the Hasbrouck upper bound and HMW information shares on a constant, the time trend, and a dummy variable,

$$\ln(IS_{1,t}/(1 - IS_{1,t})) = c + b_4 \times Trend + b_5 D_{i,t} + \varepsilon_t. \quad (28)$$

$D_{i,t} = 1$ for days of the 11 announcements and zero otherwise. We use information shares computed earlier for the entire trading day, 8:20 to 15:00. Results for all three maturities are in Table 4.

We also test whether the announcements influence information shares through spreads and trades—or whether their effects are independent of those liquidity variables—by adding an announcement indicator to the model (26),

$$\begin{aligned} \ln(IS_{1,t}/(1 - IS_{1,t})) = & c + b_1 \ln(S_{1,t}/(S_{1,t} + S_{2,t})) + b_2 \ln(N_{1,t}/(N_{1,t} + N_{2,t})) + \\ & b_3 \ln(RV_{1,t}/(RV_{1,t} + RV_{2,t})) + b_4 \times Trend + b'_5 D_{i,t} + \varepsilon_t. \end{aligned} \quad (29)$$

[INSERT Table 4 HERE]

Table 4 displays the results of (28) and (29). The odd numbered columns of Table 4 show the coefficients, b_5 , on the 8 macro and 3 FOMC announcements, obtained by estimating (28). The dependent variables were the transformations of the H_U measure (upper panel) and HMW shares (lower panel). The boldfaced coefficients are statistically significant at the 5% level. The top panel of Table 4 reveals that jobless claims, CPI, durables, PPI and non-farm payrolls are significant announcements. The CPI, PPI and payrolls are all significantly negative for the 5- and 10-year Hasbrouck shares. Jobless claims and PPI are significantly negative for the HMW shares for the 5- and 10-year markets. Nonfarm payrolls and the unscheduled FOMC announcements for the 2-year HMW share are the only coefficients which are significantly positive.

In summary, in 15 of 48 cases, macro announcements significantly lower the relative GovPX share of price discovery during the business day of the macro announcement. This shift in price

discovery is especially likely to happen for the 5- and 10-year instruments. The declines are modest though. Over all announcements, the declines average 3.76% for the H_U and 0.70% for the HMW .¹⁵ This does not indicate a dramatic preference for the futures market. Nevertheless, the statistically significant variables are associated with average declines of 3 to 16% in the GovPX information shares.

The even numbered columns of Table 4 show the coefficients b'_5 on the macro and FOMC announcements in (29). There are only 4 of 66 statistically significant regression coefficients after the inclusion of spreads, trades and realized volatility. The positive coefficients on non-farm payrolls and the unscheduled FOMC announcements for the 2-year note are no longer significant. For the H_U measure of price discovery, the only significant impact remaining is durables for the 2-year note. The decline in statistical significance for macro announcements in (29) indicates that relative liquidity and volatility subsume the explanatory impact. Of course, the news releases can be predicted in advance, while the changes in relative liquidity/volatility are much less predictable.

To check the robustness of these results, we recomputed information shares for the 1-hour interval after typical macro announcement times, 8:30 - 9:30 a.m.. That is, we computed information shares, spreads, trade volume and volatility in a one-hour window and recomputed the regression results from (28) and (29) to see if announcements and liquidity measures explain information shares within this narrow window. While we omit the full results for the sake of brevity, we find that as one might expect, news releases have a greater impact on information shares in a narrow window after announcements. Information shares for the spot market are significantly lower in the morning window for 20 of 48 macro announcements. The average impact on price shares over the 20 significant announcements range from 4 to 18 percent. After controlling for spreads, trades and volatility, however, only 7 announcements are significant. Again, the relative liquidity/volatility variables subsume the information about releases. The most pertinent event is again the CPI with 3 significant negative coefficients, even after the inclusion of liquidity variables.

We think this provides some perspective on the results in this paper compared to the prior literature. Information shares of the more highly leveraged futures markets do often rise modestly but in a predictable way, consistent with changes in relative liquidity and volatility.

¹⁵ We computed the average declines directly; they are not shown in the tables for the sake of brevity.

7. Conclusion

This paper has examined three very active spot and futures markets: the 2- and 5-year spot notes and 10-year spot bonds, and the corresponding futures markets. We analyzed high-frequency tick data from the GovPX trading platform and the Chicago Board of Trade over the period 1995-2001.

This paper is the first to investigate information shares in the price discovery process in the U.S. bond market across a range of maturities, in both spot and futures markets. We employed bivariate VECM systems to estimate information shares for the common component of bond prices of similar maturities. GovPX information shares are highest in the 2-year note where futures market trading is the least active. The GovPX market's information shares rise from 1995 to 1998 for all instruments, but then decline significantly. By 2001, the Hasbrouck information share lower bound, H_L , for GovPX is only 22% in the 5-year and 14.5% in the 10-year. Only in the 2-year note does the GovPX spot market maintain the bulk of price discovery. The H_L for the GovPX 2-year note declines from 72% in 1998 to only 55% in 2001. The importance of the futures market in all periods suggests that bond-market studies that exclude this market might be misleading or incomplete.

We also provide a new result that standard liquidity measures, including the number of trades, relative bid-ask spreads, and realized volatility strongly explain daily bond-market information shares in an economically sensible way. The GovPX information shares decline in a statistically significant fashion during days of a number of macroeconomic news releases. This effect is even stronger in a one-hour window after the times of macroeconomic news releases. Days of macroeconomic announcements rarely predict information shares independently of their effects through the liquidity and volatility measures, however.

Our results illustrate that both transitory factors, such as daily variation in liquidity, volatility and macroeconomic announcements, and long-term trends, such as the movement to electronic markets, influence price discovery.

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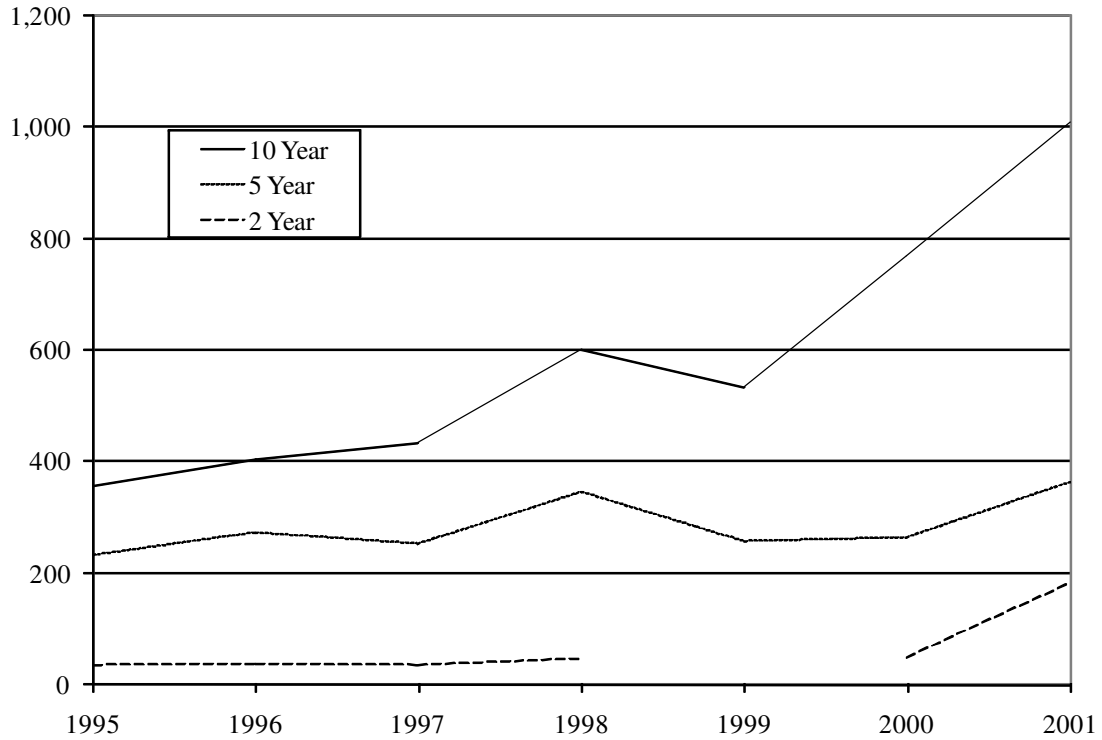
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Figure 1
GovPX Trading Activity



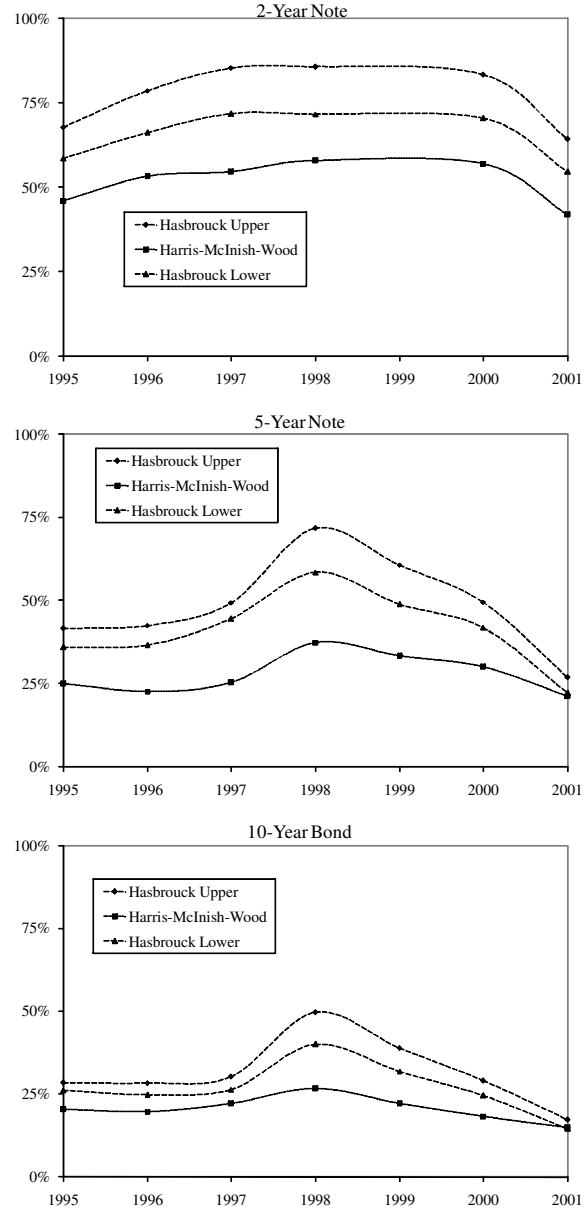
Notes: The entries are annual averages of daily trading volume from the GovPX trading platform. The *on-the-run* Treasury security is the most recently auctioned security of that maturity. The rest are considered *off-the-run*. The *when-issued* market consists of trading in securities that are about to be auctioned.

Figure 2
Futures Market Trading Activity



Notes: We report annual average trading activity in the 2-, 5-, and 10-year CBOT futures contracts. The calculations are based on a continuous futures contract, assuming that contracts rollover on the first day of the expiration month. The CBOT 2-year futures data for 1999 are incomplete, so we do not report an average for that year.

Figure 3
Spot Market Information Shares, 1995-2001



Notes: The figures show the annual averages of the daily information share estimates for the spot market. We use 1-minute returns. The upper-bound Hasbrouck information share (18), places the spot market first in a bivariate system, and the lower-bound places it second. The Harris-McInish-Wood information share is given by (20).

Table 1
VAR Estimates

| <i>2-year</i> | H_U | HMW | H_L | β | α_1 | α_2 |
|----------------|------------------|------------------|------------------|------------------|------------------|-------------------|
| 1995 | 0.678 (0.032) | 0.460 (0.020) | 0.585 (0.028) | 0.906 (0.010) | 0.065 (0.007) | 0.041 (0.003) |
| 1996 | 0.785 (0.018) | 0.533 (0.010) | 0.661 (0.017) | 0.908 (0.008) | 0.060 (0.003) | 0.046 (0.002) |
| 1997 | 0.853 (0.013) | 0.546 (0.008) | 0.718 (0.013) | 0.923 (0.007) | 0.046 (0.003) | 0.044 (0.002) |
| 1998 | 0.857 (0.018) | 0.579 (0.016) | 0.716 (0.015) | 0.911 (0.030) | 0.056 (0.192) | 0.043 (0.006) |
| 2000 | 0.833 (0.014) | 0.570 (0.009) | 0.703 (0.013) | 0.903 (0.004) | 0.051 (0.003) | 0.047 (0.002) |
| 2001 | 0.642 (0.045) | 0.419 (0.015) | 0.546 (0.041) | 0.931 (0.004) | 0.101 (0.008) | 0.050 (0.005) |
| <i>5-year</i> | H_U | HMW | H_L | β | α_1 | α_2 |
| 1995 | 0.415 (0.029) | 0.249 (0.015) | 0.358 (0.000) | 0.983 (0.006) | 0.192 (0.008) | 0.052 (0.005) |
| 1996 | 0.425 (0.012) | 0.226 (0.007) | 0.365 (0.013) | 0.985 (0.002) | 0.220 (0.006) | 0.051 (0.003) |
| 1997 | 0.493 (0.014) | 0.253 (0.008) | 0.444 (0.014) | 0.989 (0.004) | 0.227 (0.003) | 0.060 (0.003) |
| 1998 | 0.716 (0.011) | 0.374 (0.010) | 0.585 (0.011) | 0.985 (0.003) | 0.129 (0.006) | 0.054 (0.004) |
| 1999 | 0.606 (0.017) | 0.333 (0.009) | 0.488 (0.015) | 0.961 (0.002) | 0.133 (0.005) | 0.060 (0.005) |
| 2000 | 0.494 (0.017) | 0.300 (0.010) | 0.418 (0.019) | 0.959 (0.005) | 0.173 (0.008) | 0.068 (0.002) |
| 2001 | 0.269 (0.028) | 0.213 (0.018) | 0.221 (0.034) | 0.959 (0.005) | 0.124 (0.003) | 0.031 (0.004) |
| <i>10-year</i> | H_U | HMW | H_L | β | α_1 | α_2 |
| 1995 | 0.284 (0.024) | 0.204 (0.013) | 0.261 (0.029) | 0.993 (0.004) | 0.184 (0.007) | 0.042 (0.004) |
| 1996 | 0.282 (0.014) | 0.196 (0.008) | 0.246 (0.013) | 0.994 (0.002) | 0.166 (0.003) | 0.037 (0.002) |
| 1997 | 0.302 (0.010) | 0.221 (0.007) | 0.264 (0.009) | 0.999 (0.003) | 0.157 (0.003) | 0.0360 (0.003) |
| 1998 | 0.496 (0.016) | 0.266 (0.014) | 0.400 (0.021) | 0.993 (0.015) | 0.119 (0.059) | 0.032 (0.004) |
| 1999 | 0.388 (0.009) | 0.221 (0.010) | 0.318 (0.013) | 0.987 (0.002) | 0.101 (0.004) | 0.021 (0.004) |
| 2000 | 0.290 (0.013) | 0.183 (0.009) | 0.244 (0.013) | 0.972 (0.003) | 0.137 (0.004) | 0.024 (0.002) |
| 2001 | 0.172 (0.026) | 0.148 (0.015) | 0.145 (0.016) | 0.975 (0.009) | 0.108 (0.006) | 0.014 (0.001) |

Notes: The table shows the annual averages of the daily information share estimates for the GovPX spot market. We use 1-minute returns. H_U is the Hasbrouck information share (18), with the spot market first in a bivariate system, and H_L places it second. HMW is the Harris-McInish-Wood information share (20). β , α_1 and α_2 are the parameters from the VAR system (5) and (6). Bootstrap standard errors are in parentheses.

Table 2
Speeds of Adjustment

GovPX Spot Market

| | 2-year | | 5-year | | 10-year | |
|-------------------|---------------|--------|---------------|--------|----------------|--------|
| | Min | Max | Min | Max | Min | Max |
| Year | 2001 | 1995 | 2000 | 2001 | 1995 | 2001 |
| α_2 | 0.0496 | 0.0409 | 0.0680 | 0.0314 | 0.0424 | 0.0139 |
| Half-Life (mins.) | 14 | 17 | 10 | 22 | 16 | 49 |

CBOT Futures Market

| | 2-year | | 5-year | | 10-year | |
|-------------------|---------------|--------|---------------|--------|----------------|--------|
| | Min | Max | Min | Max | Min | Max |
| Year | 2001 | 1997 | 1997 | 1998 | 1995 | 2001 |
| α_1 | 0.1006 | 0.0458 | 0.2269 | 0.1287 | 0.1838 | 0.1083 |
| Half-Life (mins.) | 7 | 15 | 3 | 6 | 4 | 7 |

Notes: The table reports maximum and minimum half lives implied by the daily average partial adjustment coefficients in the GovPX spot market, α_2 and the CBOT futures market, α_1 . Half-lives are the expected number of minutes for 50% of a shock to the spot market to dissipate.

Table 3
Models for the Information Share

| Mat. | Hasbrouck | | | | | | HMW | | | | | |
|---------|-------------------------|------------------------|-----------------------|------------------------|-----------------------|-------|------------------------|------------------------|-----------------------|------------------------|-----------------------|-------|
| | Const. | Spreads | Trades | RV | Trend | R^2 | Const. | Spreads | Trades | RV | Trend | R^2 |
| 2-year | -0.18 (0.61) | -1.14 (0.57) | 3.08 (0.66) | -3.02 (0.60) | 0.18 (0.07) | 0.05 | -3.15 (0.30) | -2.60 (0.28) | 0.88 (0.33) | -1.21 (0.30) | 0.11 (0.03) | 0.13 |
| 5-year | -11.39 (0.97) | -9.63 (0.97) | 0.34 (0.52) | -3.11 (0.96) | 0.54 (0.06) | 0.21 | -6.37 (0.55) | -3.16 (0.54) | 0.49 (0.29) | -2.44 (0.54) | 0.28 (0.04) | 0.13 |
| 10-year | -6.61 (0.61) | -2.55 (0.49) | 1.26 (0.21) | -4.46 (0.63) | 0.67 (0.06) | 0.15 | -5.20 (0.38) | -1.58 (0.31) | 0.36 (0.13) | -2.63 (0.40) | 0.26 (0.04) | 0.09 |

Notes: The table reports estimates of (26). The dependent variable is a transformation ($\ln(IS/(1 - IS))$) of the Hasbrouck upper bound or Harris-McInish-Wood (right panel) information share for the spot market in a bivariate system with the maturity matched futures market. Regressions use daily data from October 1, 1995, to March 30, 2001. Standard errors are in parentheses. Bold type indicates coefficients that are statistically significant at the 5 percent level.

Table 4
Impact on Information Share of Macro Announcements

| Macro | Hasbrouck | | | | | |
|--------------|---------------|---------------|---------------|--------|---------------|---------------|
| | 2-year | | 5-year | | 10-year | |
| | b_5 | b'_5 | b_5 | b'_5 | b_5 | b'_5 |
| Jobless | -0.042 | -0.071 | -0.340 | -0.127 | -0.289 | -0.151 |
| CPI | 0.379 | 0.346 | -0.753 | -0.137 | -0.564 | -0.163 |
| Durables | -1.224 | -1.275 | -0.440 | -0.251 | -0.206 | 0.004 |
| Housing | -0.230 | -0.267 | -0.280 | -0.158 | -0.393 | -0.349 |
| Leading Ind. | 0.061 | 0.000 | 0.111 | 0.249 | 0.295 | 0.369 |
| Trade | -0.086 | -0.008 | -0.031 | -0.134 | 0.045 | 0.005 |
| Payrolls | 0.313 | -0.052 | -1.423 | -0.020 | -0.655 | 0.167 |
| PPI | 0.607 | 0.416 | -1.301 | -0.556 | -0.866 | -0.392 |
| FOMC | | | | | | |
| Announcement | 0.202 | 0.241 | -0.762 | -0.430 | -0.483 | -0.505 |
| Minutes | 0.375 | 0.512 | -0.021 | 0.245 | -0.463 | -0.338 |
| Unscheduled | -0.300 | -0.379 | -1.223 | -0.244 | -0.538 | -0.057 |
| Macro | HMW | | | | | |
| | 2-year | | 5-year | | 10-year | |
| | b_5 | b'_5 | b_5 | b'_5 | b_5 | b'_5 |
| Jobless | -0.137 | -0.218 | -0.237 | -0.138 | -0.243 | -0.178 |
| CPI | 0.199 | 0.136 | -0.564 | -0.326 | -0.311 | -0.106 |
| Durables | -0.950 | -0.992 | -0.262 | -0.190 | -0.084 | 0.031 |
| Housing | -0.070 | -0.028 | -0.182 | -0.115 | -0.255 | -0.221 |
| Leading Ind. | 0.145 | 0.081 | 0.190 | 0.257 | 0.216 | 0.258 |
| Trade | 0.102 | 0.141 | 0.094 | 0.054 | 0.047 | 0.033 |
| Payrolls | 0.378 | -0.002 | -0.306 | 0.247 | -0.377 | 0.030 |
| PPI | 0.258 | 0.119 | -0.389 | -0.095 | -0.450 | -0.211 |
| FOMC | | | | | | |
| Announcement | 0.085 | 0.035 | -0.148 | -0.028 | 0.168 | 0.142 |
| Minutes | 0.252 | 0.371 | -0.259 | -0.158 | -0.249 | -0.205 |
| Unscheduled | 2.332 | 2.080 | 0.134 | 0.548 | -0.235 | -0.088 |

Notes: The table reports estimates of (28) in the first, third and fifth columns and those from (29) in the second, fourth and sixth columns. The dependent variable is a transformation ($\ln(IS/(1 - IS))$) of the Hasbrouck upper bound (first panel) or Harris-McInish-Wood (second panel) information share for the GovPX market. The odd columns (labeled b_5) report results from estimates that do not control for daily liquidity (28), and the even columns (labeled b'_5) add relative spreads, trades and volatility (29). Regressions use daily data from October 1, 1995, to March 30, 2001. Bold type indicates coefficients that are statistically significant at the two-sided 5 percent level.